524 Rec'd PCT/PTO 13 OCT 1999

FORM PTO-1390 (REV. 5-93)

U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER
518-1006

U S APPLICATION NO (If known, see 37 C.F R 1.5)
09/402955

INTERNATIONAL APPLICATION NO	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/FR98/00735	April 10, 1998	April 14, 1997

TITLE OF INVENTION
Space-Weighted Communication Path Estimation

APPLICANT(S) FOR DO/EO/US
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Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. X This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.

2. _ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.

3. _ This express request to begin national examination procedures (35 U.S.C. 371(f) at any time rather than delay examination until the expiration of the applicable time limit set in 37 U.S.C. 371(b) and PCT Articles 22 and 39(1).

4. X A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.

5. X A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. X is transmitted herewith (required only if not transmitted by the International Bureau).
   b. _ has been transmitted by the International Bureau.
   c. _ is not required, as the application was filed in the United States Receiving Office (RO/US).

6. _ A translation of the International Application into English (35 U.S.C. 371(c)(2)).

7. X Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. _ are transmitted herewith (required only if not transmitted by the International Bureau).
   b. _ have been transmitted by the International Bureau.
   c. _ have not been made; however, the time limit for making such amendments has NOT expired.
   d. X have not been made and will not be made.

8. _ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).

9. _ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).

10. _ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. _ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.

12. _ An assignment document for recording A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.

13. _ A FIRST preliminary amendment.
    _ A SECOND or SUBSEQUENT preliminary amendment.

14. _ A substitute specification.

15. _ A change of power of attorney and/or address letter.

16. _ Other items or information:

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U.S. APPLICATION NO. (If know, see 37 C.R.R. 1.50)	INTERNATIONAL APPLICATION NO.	ATTORNEY'S DOCKET NUMBER	
09/402955	PCT/FR98/00735	518-1006	

17. X The following fees are submitted:				CALCULATIONS	PTO USE ONLY
Basic National Fee 37 CFR 1.492(a)(1)-(5)): Search Report has been prepared by the EPO or JPO . . . . $840.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) . $670.00 No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) . . . . $760.00 Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO . . . . $970.00 International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) $96.00					
ENTER APPROPRIATE BASIC FEE AMOUNT =				$840	
Surcharge of **$130.00** for furnishing the oath or declaration later than _ 20 _ 30 months from the earliest claimed priority date (37 CFR 1.492(e)).					
Claims	Number Filed	Number Extra	Rate		
Total Claims	14 - 20 =	0	X $18.00	0	
Independent Claims	1 - 3 =	0	X $78.00	0	
Multiple dependent claim(s) (if applicable)			+ $260.00	260	
TOTAL OF ABOVE CALCULATIONS =				1110	
Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed. (Note 37 CFR 1.9, 1.27, 1.28).				----------	
SUBTOTAL =				1110	
Processing fee of **$130.00** for furnishing the English translation later than _ 20 _ 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				----------	
TOTAL NATIONAL FEE =				1110	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +				----------	
TOTAL FEES ENCLOSED =				1110	
				Amount to be refunded:	
				Charged	

a. X A check in the amount of $ 1110 to cover the above fees is enclosed.
b. _ Please charge my Deposit Account No. 12-0913 in the amount of $__ to cover the above fees. A duplicate copy of this sheet is enclosed.
c. X The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 12-0913 . A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate lime limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

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PTO/PCT Rec'd 14 FEB 2000

SPACE-WEIGHTED COMMUNICATION PATH ESTIMATION

The present invention relates to a method of estimating a communication path formed by a plurality of channels. Thus it relates to a technique referred to as reception diversity, whereby a receiver has a plurality of antennas each associated with a different communication channel. In other words, the invention proposes a method of estimating the impulse responses of the transmission channels.

In a communications system, especially a radio communications system, the receiver receives for each communication channel a signal transmitted by a transmitter. The transmitted signal is subject to amplitude and phase fluctuations in the communication channel with the result that the signal received by the receiver is not identical to the transmitted signal. Signal fluctuations are essentially due to what the skilled person refers to as intersymbol interference. This interference can result from the modulation law employed for transmission and is also caused by multipath propagation in the channel.

It is found that the received signal is generally the result of a large number of reflections in the channel. The various paths taken by the transmitted signal cause various delays at the receiver. The impulse response of the channel represents all such fluctuations affecting the transmitted signal. It is therefore the fundamental characteristic representative of transmission between the transmitter and the receiver.

The impulse response of the channel is used in particular by an equalizer whose precise function is to correct intersymbol interference in the receiver. A standard method of estimating the impulse response consists in placing a training sequence made up of known symbols in the transmitted signal.

The sequence is chosen as a function of the modulation law and the dispersion of the channel. In the

present context, "dispersion" is to be understood as meaning the delay affecting a transmitted symbol taking the longest path of the channel relative to the same symbol taking the shortest path. The dispersion is routinely expressed as a multiple of the time between two successive transmitted symbols, i.e. a number of "symbol periods".

Two examples of prior art techniques for estimating the impulse response of a communication channel are mentioned.

The first technique uses particular training sequences referred to as constant amplitude zero autocorrelation (CAZAC) sequences. These sequences are described in an article by A. MILEWSKI: "Periodic sequences with optimal properties for channel estimation and fast start-up equalization", IBM Journal of Research and Development, Vol.27, No.5, Sept. 83, pages 426-431.

The GSM cellular mobile radio system uses training sequences TS made up of 26 symbols a_0 to a_{25} taking the value +1 or -1. These sequences have the following properties:

$$\sum_{i=5}^{20} a_i^2 = 16$$

$$\sum_{i=5}^{20} a_i a_{i+k} = 0 \qquad \text{if } 0 < |k| \leq 5$$

Letting <u>d</u> denote the dispersion of the channel, which takes the value 4 in GSM, the estimate of the impulse response takes the form of a vector X with five components x_0 to x_4.

The received symbol sequence S corresponding to the training sequence TS is also made up of 26 symbols, denoted s_0 to s_{25}. The natural assumption is made here that the transmitter and the receiver are perfectly synchronized, in which case the estimate of the impulse response X is given by the following expression:

$$X_k = \frac{1}{16}\sum_{i=5}^{20} a_i s_{i+k} \qquad \text{for } 0 \le k \le 4$$

The CAZAC technique has the advantage that it is very simple to implement. However, it should be noted that each component of the impulse response is established from only 16 received symbols. Because the training sequence is made up of 26 symbols and the channel dispersion value is 4, there is information in the received signal that is not taken into account and this degrades performance compared to the theoretical ideal.

The second prior art technique uses the least squares criterion. It is described in particular in patent applications FR 2 696 604 and EP 0 564 849. It uses a measurement matrix A constructed from a training sequence TS of length n. The matrix has (n-d) rows and (d+1) columns, where d again represents the dispersion of the channel. The item in the ith row and the jth column is the (d+i-j)th symbol of the training sequence:

$$A = \begin{pmatrix} a_4 & a_3 & a_2 & a_1 & a_0 \\ a_5 & a_4 & a_3 & a_2 & a_1 \\ a_6 & a_5 & a_4 & a_3 & a_2 \\ a_7 & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{25} & \cdots & \cdots & \cdots & a_{21} \end{pmatrix}$$

The training sequence is chosen so that the matrix A^tA, where the operator $.^t$ represents transposition, cannot be inverted. This is inherently the case for CAZAC sequences but is also the case for other sequences.

The first four symbols s_0 through s_3 in the sequence of received symbols are ignored because they also depend on unknown symbols transmitted before the training sequence, given that the value of the channel dispersion is 4. At the risk of using a misnomer, the received

signal will therefore be defined as a vector S whose components are the received symbols s_4, s_5, s_6, ..., s_{25}.

The estimate of the impulse response then takes the following form:

$$X = (A^tA)^{-1}A^t.S$$

This least squares technique is slightly more complex than the preceding technique but it should be noted that the matrix $(A^tA)^{-1}A^t$ is calculated only once. Note also that each component of the estimate of the impulse response X is obtained from 22 received symbols, rather than 16 as in the CAZAC technique. Improved performance can therefore be expected.

However, regardless of the technique used, the impulse response of each channel of the communication path is considered to be independent of the others.

A first object of the present invention is therefore to provide a method of estimating a communication path which takes into account the fact that the various antennas are spatially linked.

The method in accordance with the invention of estimating a communication path is used when the path is formed of a plurality of channels and the method necessitates an estimate of the impulse responses C_1, C_2, ..., C_n of said channels. The method includes the following steps:

- acquiring a space statistic of the transmission path,
- establishing a corrected impulse response at least by weighting said impulse response estimates by means of said space statistic and an estimate of the additive noise of said channels.

The space statistic advantageously corresponds to an estimate of the correlation of the communication channels taken two by two.

In a preferred embodiment of the invention the estimate of the correlation of the communication channels takes the form of a space correlation matrix in which the element in the ith row and the jth column is obtained by

smoothing the product of the Hermitian transposition of the estimated impulse response of the ith channel and the estimated impulse response of the jth channel.

According to an additional feature of the invention a signal S received by a channel corresponds to a transmitted training sequence and the estimate of the additive noise N_{01} of that channel is obtained by normalizing the energy of the vector $(S - AC_1)$ where A is the measurement matrix associated with said training sequence.

The normalization can followed by an averaging step.

Also, if a noise matrix N is formed from the estimated additive noise N_{01}, N_{02}, ..., N_{0n} of the channels and a space-weighting matrix G′ is defined on the basis of said spatial correlation matrix G and said noise matrix $G' = G(G + N)^{-1}$, said corrected impulse responses C'_1, C'_2, ..., C'_n are obtained from the following expression:

$$\begin{pmatrix} C'^{\,t}_1 \\ C'^{\,t}_2 \\ \cdot \\ \cdot \\ \cdot \\ C'^{\,t}_n \end{pmatrix} = G' \begin{pmatrix} C^t_1 \\ C^t_2 \\ \cdot \\ \cdot \\ \cdot \\ C^t_n \end{pmatrix}$$

The method of estimating a communication path is therefore based on the estimate of the impulse response of the various channels considered as independent channels. Estimation errors are inevitable. As a general rule, determining the impulse response of a single communication channel is a problem that cannot be solved exactly in the presence of additive noise. Also, the prior art techniques implicitly assume that the impulse response can take any form.

Accordingly, a second object of the invention is to provide a method of estimating the impulse response of a

communication channel which has improved response to additive noise, in other words which leads to an error lower than the estimation error of prior art techniques. This method is advantageously applied to at least one of the channels forming the communication path before establishing impulse responses corrected by weighting by means of the space statistic and an estimate of the additive noise of the channels.

According to the invention, this method requires a signal received by a channel and corresponding to a transmitted training sequence. The method includes the following steps:

- acquiring a time statistic of the transmission channel,
- establishing the estimate of the impulse response of said channel, which estimate is weighted by said time statistic of the channel by means of said received signal.

The time statistic of the channel represents a value of the impulse response prior to acquisition of the received signal. Said weighting introduces the fact that the impulse response related to the received signal has a value which is probably closer to that prior value than a value very far away from it. Thus the estimation error is reduced from the statistical point of view.

The time statistic advantageously corresponds to an estimate of the covariance of said impulse response.

A first variant of the method includes the following steps:

- smoothing said impulse response and orthonormalizing by means of a transformation matrix W to obtain said estimate of the covariance which then takes the form of a matrix L',
- seeking eigenvectors v_i' and eigenvalues λ_i' associated with that matrix L',
- estimating the instantaneous impulse response of the channel from said received signal and applying that transformation matrix W to form a vector X', so

establishing said weighted estimate Xp:

$$X_p = \sum\left(\frac{\lambda_i' - N_0}{\lambda_i'}(v_i'^h . X')\right) W v_i'^h$$

where N_0 is a positive real number representing the additive noise of said channel.

The additive noise can be made equal to the smallest of said eigenvalues λ_i'.

Each eigenvalue of a subset of said eigenvalues λ_1' having a contribution less than a predetermined threshold can be forced to the value of said additive noise.

This reduces the complexity commensurately.

In a second variant of the method the estimate of the covariance takes the form of a matrix R and said weighted estimate is established as follows:

$$Xp = (A^t A + N_0 R^{-1})^{-1} A^t . S$$

where A is the measurement matrix associated with said training sequence and N_0 is a positive real number representing the additive noise of said channel.

The method can include a step of orthonormalizing said matrix R by means of a transformation matrix W to obtain a new matrix R', the weighted estimate then taking the following new form:

$$Xp = W^t (I + N_0 R'^{-1})^{-1} W^t A'^t . S$$

where the matrix A' is equal to product of the transformation matrix W and said measurement matrix A.

The expression $(I + N_0 R'^{-1})^{-1}$ is advantageously calculated by means of the matrix inversion lemma.

The present invention will emerge in more detail from the following description of embodiments of the invention which is given by way of example only and with reference to the accompanying drawings, in which:

- Figure 1 is a diagram identifying the principal steps of an implementation of a method of the invention for estimating a communication path,

- Figure 2 shows a first variant of a method of the

invention for estimating the impulse response of a channel,

- Figure 3 shows a second variant of a method of the invention for estimating the impulse response of a channel.

The invention is described as applied to GSM, because GSM has the merit of being well-known to the skilled person. Thus GSM is described in the interests of clarity, but this must not be taken as limiting the invention to this system alone.

Referring to Figure 1, the method of estimating a communication path is applied when the path includes at least two communication channels, generally _n_ channels. Each channel corresponds to a separate antenna. It is assumed that an estimate of the respective impulse responses C_1, C_2, ..., C_n of each of the channels has been arrived at using any of the available techniques.

The method first acquires a space statistic of the communication path. The expression "space statistic" refers to a set of data reflecting the behavior of the path over a predetermined period referred to as the correlation period. Because the various antennas are fixed, the signals received at the antennas have some degree of correlation. The invention aims specifically to exploit this fact to improve the quality of the estimate of the impulse response of at least one channel. For example, this statistic can be obtained by means of a spatial correlation matrix G:

$$G = \begin{pmatrix} V(C_1^hC_1) & V(C_1^hC_2) & \cdots\cdots & V(C_1^hC_n) \\ V(C_2^hC_1) & V(C_2^hC_2) & \cdots\cdots & V(C_2^hC_n) \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ V(C_n^hC_1) & V(C_n^hC_2) & \cdots\cdots & V(C_n^hC_n) \end{pmatrix}$$

where the operator $.^h$ represents the Hermitian

transposition.

The square matrix G with dimensions (n,n) can therefore be represented generically by the element g_{ij} in the ith row and the jth column:

$$G_{ij} = V(C^h{}_iC_j)$$

The element g_{ij} is obtained by smoothing the product $C^h{}_iC_j$ using the estimated impulse responses C_i, C_j of the ith and jth channels obtained during the correlation period. This smoothing is an estimate of the correlation of the two channels.

Here "smoothing" is to be understood in a very general sense, meaning any operation for smoothing or averaging the product $C^h{}_iC_j$ over the correlation period.

A first example of smoothing consists in averaging the product over the correlation period:

$$V(C_i^hC_j) = \frac{1}{e}\sum_1^e C_i^hC_j$$

The correlation period is assumed to include e successive estimates of each of the impulse responses C_1, C_2, ..., C_n.

A second example of smoothing consists in updating, at the pth estimate received for each of the ith and jth channels, the smoothing expression $V_{p-1}(C^h{}_iC_j)$ obtained at the (p - 1)th estimation by means of a multiplier coefficient α which has a value from 0 to 1 and is often referred to as the smoothing forget factor:

$$V_p(C^h{}_iC_j) = \alpha C^h{}_iC_j + (1-\alpha)V_{p-1}(C^h{}_iC_j)$$

Initialization can be effected by any means, in particular using the first estimate obtained or an average for the first estimates received obtained as in the first example.

The estimation method then proposes to estimate the additive noise N_{01}, N_{02}, ..., N_{0n} present in each of the channels by means of the estimates of the respective impulse responses C_1, C_2, ..., C_n of the channels.

Various solutions for obtaining this estimate of the

noise are proposed and the case of a single channel, for example the first channel, is discussed, given that the same solutions apply to each channel.

A simple solution assigns N_{01} a predetermined value which reflects a threshold below which it is considered to be unlikely that the additive noise can descend. This value can be determined by measuring a signal to noise ratio or from the performance of the receiver, for example.

Also, the noise N_{01} can be estimated by means of the estimate of the impulse response C_1 of the first channel and the corresponding received signal S. Thus the noise can be estimated before applying the space-weighted estimation method, regardless of which technique is used. Nevertheless, if this were not the case, there is proposed here a method which is appropriate if the estimate of the impulse response C_1 is acquired using the least squares technique.

It is therefore a matter of estimating the additive noise directly from the received signal S and the measurement matrix A. Letting N_1 denote the noise vector affecting the received signal:

$$S = AC_1 + N_1$$

The estimate of the noise N_{01} takes the form:

$$N_{01} = \left(\frac{1}{22}\right) (S - AC_1)^h (S - AC_1)$$

because the vectors S and N_1 have 22 components.

This estimate of the additive noise N_{01} can naturally be averaged or smoothed.

A noise matrix N in which n_{ij} denotes the element in the ith row and the jth column is constructed from the estimates of the additive noise $N_{01}, N_{02}, \ldots, N_{0n}$ of the various channels.

If <u>i</u> is equal to <u>j</u>, the element n_{ij} takes the value of the estimated noise N_{0i}.

If <u>i</u> and <u>j</u> are different, the element n_{ij} is a null

element.

Also, and again in the interests of simplification, it is possible to calculate the average value N_0 of the estimated noise N_{01}, N_{02}, ..., N_{0n} and to force each element n_{ij} on the diagonal of the matrix N to that average value N_0. Letting I denote the identity matrix, it follows that the noise matrix N takes the following form:

$$N = N_0 I$$

The correlation matrix G and the noise matrix N are used to define a new matrix, namely the space weighting matrix G':

$$G' = G(G + N)^{-1}$$

The impulse responses C'_1, C'_2, ..., C'_n corrected by means of the space weighting matrix G' are therefore defined as follows:

$$\begin{pmatrix} C'^{t}_{1} \\ C'^{t}_{2} \\ . \\ . \\ . \\ C'^{t}_{n} \end{pmatrix} = G' \begin{pmatrix} C^{t}_{1} \\ C^{t}_{2} \\ . \\ . \\ . \\ C^{t}_{n} \end{pmatrix}$$

where $.^t$ again represents the transposition operator.

At least one of the corrected impulse responses C'_1 is used instead of the estimate of the impulse response C_1 in the receiver.

The invention offers the option of improving the estimate of the impulse response C_1, C_2, ..., C_n of each channel before applying the space-weighted method of estimating a communication path, i.e. before establishing the corrected impulse response(s) C'_1, C'_2, ..., C'_n.

A time statistic is therefore acquired for at least one of these channels, for example the first channel. The expression "time statistic" refers to a set of data reflecting the behavior of the channel concerned,

independently of the other channels and over a predetermined period referred to as the analysis period. It is therefore a representation of the average behavior of the channel during the analysis period. This statistic can be established by any means and anywhere. The statistic can be established in any equipment unit of the radio communication network. What is important is that the receiver is able to acquire this statistic.

A time statistic of this kind can be obtained in the following manner, for example.

Using a method known in the art, an estimate X of the impulse response is calculated from the signal S received during the analysis period.

If the least squares technique is adopted, the value of this estimate X is:

$$X = (A^t A)^{-1} At.S \qquad (1)$$

It must be remembered that the transmitter and receiver are assumed to be synchronized to within better than half a symbol, in which case the received signal is the vector S whose components are the received symbols s_4 to s_{25} synchronous with the symbols a_4 to a_{25} of the training sequence TS. Several solutions are available for acquiring this synchronization, if not acquired already, and two examples of these will be mentioned.

The first solution consists in advancing or delaying the received signal by j symbol periods so that $s_j^t = (s_{4-j}, s_{5-j}, s_{6-j}, \ldots, s_{25-j})$.

The estimate X_j is then calculated for each vector S_j and the value j_M for which $X_j^h.X_j$ is a maximum is adopted. This value j_M gives the expected synchronization and it is sufficient to replace the vector S in equation (1) with the vector S_{jM}.

The second solution artificially increases the dispersion d of the channel by a predetermined quantity 2q. A modified measurement matrix A_m can then be defined with (n-d-2q) rows and (d+2q+1) columns. Assigning n and d the respective values 26 and 4:

$$A_m = \begin{pmatrix} a_4+2_q \ldots a_4 & a_3 & a_2 & a_1 & a_0 \\ a_5+2_q \ldots a_5 & a_4 & a_3 & a_2 & a_1 \\ a_6+2_q \ldots a_6 & a_5 & a_4 & a_3 & a_2 \\ a_7+2_q \ldots \ldots & & & & \\ \ldots \ldots & & & & \\ \ldots \ldots & & & & \\ a_{25} \ldots \ldots & & & a_{21}-2_q & \end{pmatrix}$$

It is then necessary to reduce the number of components of the received signal S by the same quantity 2q and by convention the modified vector S_m is retained:

$$S_m^{\ t} = (s'_{4+q}, s'_{5+q}, \ldots, s'_{25-q})$$

A modified estimate X_m is therefore obtained:

$$X_m = (A_m^{\ t} A_m) A_m^{\ t} . S_m$$

The modified estimate X_m has d+2q+1 components:

$$X_m^{\ t} = (x_{-q}, \ldots, x_o, x_1, \ldots, x_4, \ldots, x_{4+q})$$

With the operator $.^*$ representing the complex conjugate, the value j_M of j between -q and +q which maximizes the following expression:

$$\sum_{k=0}^{4} x^*_{j+k} x_{j+k}$$

is then looked for.

The value j_M determines the estimate X of the impulse response for a dispersion d=4:

$$X^t = (x_{jM}, x_{jM+1}, \ldots, x_{jM+4})$$

The synchronization is deduced immediately by applying the offset j_M to the received signal S.

Equation (1) can then be applied again.

A smoothing matrix L is then constructed by smoothing the various estimates X obtained during the analysis period to obtain an estimate of the covariance associated with that impulse response. Here "smoothing" is to be understood in a very general sense, meaning any operation for smoothing or averaging the impulse response over the analysis period. This yields a statistical

representation of the behavior of the transmission channel. This smoothing can be achieved by either of the two methods proposed above, the simplest expression of the smoothing matrix L, where m corresponds to the number of training sequences over which the smoothing is calculated, being as follows:

$$L = \frac{1}{m}\sum_{1}^{m} XX^h$$

It is assumed here that the smoothing matrix can be approximated by the following equation:

$$L \approx (A^tA)^{-1}N_0 + R \qquad (2)$$

in which N_0 again represents the noise present in the communication channel or additive noise and R is a matrix that is usually referred to as the a priori statistical matrix of the channel because it represents the behavior of the channel ignoring noise.

It is also assumed that the measurement matrix A is properly conditioned, i.e. that the eigenvalues of the matrix A^tA are very close to each other. In this case, it is beneficial to normalize the vectors consisting of the measurement matrix A, but this must not be seen as limiting the invention.

For this purpose, a transformation matrix W is used such that:

$$A' = AW \text{ and } A'^tA' = I$$

where I represents the identity matrix.

Letting L' denote the matrix so defined:

$$L = WL'W^t,$$

it is found that equation (2) can now be written:

$$L' \approx N_0I + R' \qquad (3)$$

Note that in a first variant shown in Figure 2 the eigenvectors v_i' of L' and v_i of R' are identical whereas the eigenvalues λ_i' of L' and λ_i of R' are offset by N_0. Taking the same value of 4 for the dispersion of the channel, for any i from 0 to 4:

$$V_i' = V_i$$

$\lambda_i' = \lambda_i + N_0$

It is therefore apparent that the eigenvectors and eigenvalues of R′ and L can be determined in exactly the same way, provided that N_0 is known.

The step of estimating the noise will be described later to clarify the explanation, although it precedes the step explained next.

It is therefore now necessary to seek eigenvalue/eigenvector pairs for the matrix L′ or R′. This step will not be described in detail because it is well-known to the skilled person. Moreover, it goes without saying that eigenvalues whose contribution is deemed to be insignificant can be eliminated. For example, if the eigenvalues are listed in decreasing order, the lowest values whose sum is below a predetermined threshold can be eliminated.

The next step is to estimate the instantaneous impulse response X from the received signal corresponding to the last training sequence received and using any technique known in the art. Using the notation X = WX′, the latter estimate is weighted by the following method to obtain a temporal weighting X_p of the instantaneous impulse response:

$$X_p = \sum_{i=0}^{4}\left(\frac{\lambda_i}{\lambda_i + N_0}(v_i^h X')\right) W v_i$$

$$X_p = \sum_{i=0}^{4}\left(\frac{\lambda_i' - N_0}{\lambda_i'}(v_i^h X')\right) W v_i$$

To obtain the weighting X_p it is therefore necessary to estimate the additive noise N_0.

The noise can be estimated using any of the methods referred to above.

Another possibility is to consider the last (smallest) eigenvalue of the smoothing matrix L as equal to N_0:

$$\lambda_4' = N_0 \quad \text{or} \quad \lambda_4 = 0$$

Whatever method is adopted, the time weighting Xp of the estimate of the instantaneous impulse response can then be obtained as indicated above.

In a second variant, shown in Figure 3, the weighted estimate Xp is established directly as:

$$Xp = (A^tA + N_0R^{-1})^{-1}A^t.S$$

Or, using the transformation matrix W defined above:

$$Xp = W(I + N_0R'^{-1})^{-1}\, W^t\, A'^t.S \qquad (4)$$

From equation (3):

$$R' = L' = N_0I$$

Again the additive noise N_0 must be estimated.

An advantageous solution to obtaining the temporal weighting Xp is to use the following method.

The matrix R' is divided by N_0:

$$B = \frac{R'}{N_0}$$

It follows that:

$$I + N_0R'^{-1} = I + B^{-1}$$

The matrix inverting lemma is used to calculate the weighting matrix $P = (I + B^{-1})^{-1}$.

Accordingly, denoting the canonic vectors e_i, the following iteration is performed:

- initialization:

$$P = B$$

- for i varying from 0 to d (4 in this instance):

$$P = P - \frac{Pe_i(Pe_i)^h}{1 + e_i^hPe_i}$$

Because P is known, all that remains is to establish the weighting Xp from equation (4).

Note that the weighting matrix P is not necessarily calculated as each new training sequence is transmitted. It can be calculated at a slower rate because it varies at substantially the same rate as R' and thus more slowly

than the received signal S.

Note also that the weighted estimate is obtained without recourse to the instantaneous impulse response. It is produced directly from the received signal S.

Whichever variant is adopted, it is therefore the weighted estimate Xp that is advantageously used as the estimate of the impulse response C_1 to implement the space-weighted method of estimating a communication path, i.e. to produce one or more corrected impulse responses.

CLAIMS

1. A method of estimating a communication path formed of a plurality of channels, the method necessitating an estimate of the impulse response C_1, C_2, ..., C_n of said channels, characterized in that it includes the following steps:

- acquiring a space statistic of the transmission path,
- establishing a corrected impulse response (C'_1, C'_2, ..., C'_n) at least by weighting said impulse response estimates (C_1, C_2, ..., C_n) by means of said space statistic and an estimate of the additive noise (N_{01}, N_{02}, ..., N_{0n}) of said channels.

2. A method according to claim 1, characterized in that said space statistic corresponds to an estimate of the correlation of said communication channels taken two by two.

3. A method according to claim 2, characterized in that said estimate of the correlation of the communication channels takes the form of a space correlation matrix (G) in which the element (g_{ij}) in the ith row and the jth column is obtained by smoothing the product ($C^h{}_iC_j$) of the Hermitian transposition of the estimated impulse response (C_i) of the ith channel and the estimated impulse response (C_j) of the jth channel.

4. A method according to claim 3, characterized in that if a signal S received by a channel corresponds to a transmitted training sequence the estimate of the additive noise (N_0) of that channel is obtained by normalizing the energy of the vector ($S - AC_1$) where A is the measurement matrix associated with said training sequence.

5. A method according to claim 4, characterized in that said normalization is followed by an averaging step.

6. A method according to any of claims 3 to 5, characterized in that if a noise matrix (N) is formed from the estimated additive noise (N_{01}, N_{02}, ..., N_{0n}) of the channels and a space-weighting matrix (G′) is defined on the basis of said spatial correlation matrix (G) and said noise matrix $G' = G(G + N)^{-1}$, said corrected impulse responses (C'_1, C'_2, ..., C'_n) are obtained from the following expression:

$$\begin{pmatrix} C'^{t}_{1} \\ C'^{t}_{2} \\ \cdot \\ \cdot \\ \cdot \\ C'^{t}_{n} \end{pmatrix} = G' \begin{pmatrix} C^{t}_{1} \\ C^{t}_{2} \\ \cdot \\ \cdot \\ \cdot \\ C^{t}_{n} \end{pmatrix}$$

7. A method according to any of claims 1 to 6, characterized in that, if the signal (S) received by a channel corresponds to a transmitted training sequence, the method includes the following steps before establishing said corrected impulse response (C'_1) of that channel:
- acquiring a time statistic of the transmission channel,
- establishing the estimate (Xp) of the impulse response (C_1) of said channel, which estimate is weighted by said time statistic of the channel by means of said received signal (S).

8. A method according to claim 7, characterized in that said time statistic corresponds to an estimate of the covariance of said impulse response.

9. A method according to claim 8, characterized in that it includes the following steps:
- smoothing said impulse response and orthonormalizing by means of a transformation matrix W to obtain said

estimate of the covariance which then takes the form of a matrix L′,

- seeking eigenvectors (v_i') and eigenvalues (λ_i') associated with that matrix L′,
- estimating the instantaneous impulse response of the channel from said received signal (S) and applying that transformation matrix W to form a vector X′, so establishing said weighted estimate (Xp):

$$X_p = \sum \left(\frac{\lambda_i' - N_0}{\lambda_i'} (v_i'^h . X') \right) W v_i'^h$$

where N_0 is a positive real number representing the additive noise of said channel.

10. A method according to claim 9, characterized in that said additive noise (N_0) is made equal to the smallest of said eigenvalues (λ_i').

11. A method according to claim 9 or claim 10, characterized in that each eigenvalue of a subset of said eigenvalues (λ_1') having a contribution less than a predetermined threshold is forced to the value of said additive noise (N_0).

12. A method according to claim 8, characterized in that said estimate of the covariance takes the form of a matrix R and said weighted estimate (Xp) is established as follows:

$$Xp = (A^t A + N_0 R^{-1})^{-1} A^t . S$$

where A is the measurement matrix associated with said training sequence and N_0 is a positive real number representing the additive noise of said channel.

13. A method according to claim 12, characterized in that it includes a step of orthonormalizing said matrix R by means of a transformation matrix W to obtain a new

matrix R′, the weighted estimate then taking the following new form:

$$Xp = W^t(I + N_0R'^{-1})^{-1}W^tA'^t.S$$

where the matrix A′ is equal to product of the transformation matrix W and said measurement matrix A.

14. A method according to claim 13, characterized in that the expression $(I+N_0R'^{-1})^{-1}$ is calculated by means of the matrix inversion lemma.

A B S T R A C T

SPACE-WEIGHTED COMMUNICATION PATH ESTIMATION

The invention relates to a method of estimating a communication path formed of a plurality of channels, the method necessitating an estimate of the impulse response C_1, C_2, ..., C_n of said channels, characterized in that it includes the following steps:

- acquiring a space statistic of the transmission path,
- establishing a corrected impulse response (C'_1, C'_2, ..., C'_n) at least by weighting said impulse response estimates (C_1, C_2, ..., C_n) by means of said space statistic and an estimate of the additive noise (N_{01}, N_{02}; ..., N_{0n}) of said channels.

Translation of the title and the abstract as they were when originally filed by the Applicant. No account has been taken of any changes that may have been made subsequently by the PCT Authorities acting ex officio, e.g. under PCT Rules 37.2, 38.2, and/or 48.3.

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **Space-Weighted Communication Path Estimation**, the specification of which:

__ is attached hereto.

X was filed on October 13, 1999 as

Application Serial No. 09/402,955

and was amended on ________ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

PRIOR FOREIGN APPLICATION(S)

Country	Number	Date Filed	Priority Claimed Yes	Priority Claimed No
France	97/04653	April 14, 1997	X	

I hereby claim the benefit under Title 35, United States Code Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, Section 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, Section 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application.

Application Serial No.	Filing Date	Status

And I hereby appoint Thomas E. Smith, Registration No. 18,243, Dennis M. McWilliams, Registration No. 25,195, James R. Sweeney, Registration No. 18,721, William M. Lee, Jr., Registration No. 26,935, Glenn W. Ohlson, Registration No. 28,455, David C. Brezina, Registration No. 34,128, Jeffrey R. Gray, Registration No. 33,391, Timothy J. Engling, Registration No. 39,970, Gregory B. Beggs, Registration No. 19,286, Gerald S. Geren, Registration No. 24,528, Peter J. Shakula, Registration No. 40,808, William J. Lenz, Registration No. 44,208 and Robert F.J. Conte, Registration No. 20,354 to prosecute this application and to transact all business in the Patent and Trademark Office connected herewith. It is requested that all communications be directed to Lee, Mann, Smith, McWilliams, Sweeney & Ohlson, P.O. Box 2786, Chicago, Illinois 60690-2786,

(13)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

1-00

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